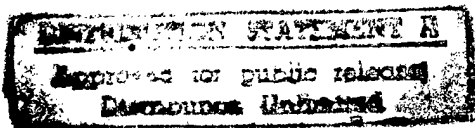


# High Performance PEM Fuel Cells - From Electrochemistry and Material Science to Engineering Development of a Multicell Stack

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# High Performance PEM Fuel Cells: From Electrochemistry and Material Science to Engineering Development of a Multicell Stack

## **1. Task 1. Advanced Membrane - Electrode Assembly (MEA) Optimization**

Investigators: Serguey Gamburgzev and Omourtag A. Velez

### Objectives

The objective of this Task is to develop MEAs capable of attaining a current density of  $0.7 \text{ A/cm}^2$  at  $0.7 \text{ V}$  with hydrogen and air as reactants at atmospheric pressure.

### **1.1 Catalysts and Electrodes**

Previous work at CESHRR has shown that platinum alloys, supported on carbon black enhance the performance of the oxygen (air) electrodes in PEMFCs. Increasing the amount of alloy, however, results in an increase of the gas transport limitation in the electrodes. This fact is illustrated in Figure 1 where a potential vs current density plot for a cell with a cathode electrocatalyst consisting of 40 wt. % PtCrCo-alloy supported on XC72 (E-TEK, Inc.) is compared with that for a cell with a Pt/C cathode, with the same Pt loading. The platinum alloy electrocatalyst has a higher electrocatalytic activity for the oxygen electrode reaction, which is further illustrated in the Tafel plot (Figure 2): at current densities above  $0.7 \text{ A/cm}^2$  the mass transport limitations make the PEMFC with the alloy electrocatalyst show a poorer performance than that of the electrode with a Pt electrocatalyst. To increase the electrocatalytic activity of the air electrode and simultaneously minimize the transport limitations, mixture of a 10 wt.% alloy supported on carbon and a high platinum loading (40 wt.%) on carbon was used as the

electrocatalyst. A comparison of the performances of PEMFCs with this mixed electrocatalyst and with Pt is shown on Figure 3. The presence of the alloy electrocatalyst enhances the electrocatalytic activity at low current densities and the presence of the Pt electrocatalyst preserves the open structure of the electrode - in this way the performance enhancement is evident over the entire range of current densities. This experiment was repeated with 20  $\mu\text{m}$  thick GORE-SELECT™ membrane and a similar effect was observed.

## 1.2 Proton Conducting Membranes

Two potential problems arise when using very thin electrolyte layers ( $\approx 20 \mu\text{m}$ ) in PEMFCs: (i) high rate of gas crossover; and (ii) the possibility of electronic shorting between the electrodes. The first effect is due to the properties of the membrane, but the second one probably occurs during MEA preparation and mounting in the cell fixtures. Either of these characteristics leads to a lower open circuit cell potential and apparently flat Tafel slopes in the low current density region of the potential vs current density plot. To avoid electronic shorting through the membrane, MEAs were prepared by the usual hot-pressing procedure, but without applying significant pressures. The electronic resistances of the MEAs were measured immediately after hot-pressing and also after assembly in the single cell test fixture. The electronic resistance of the cells was found to be dependent on the degree of compression. Compression was controlled by varying the thickness of the gasket used to bond the electrodes to the membranes. Cell potential vs current density plots for PEMFCs with different values of electronic resistance are presented on Figure 4.

The proton conducting membrane in these experiments was 20  $\mu\text{m}$  thick GORE-SELECT™. When the electronic resistance in the cell was high (larger than 1  $\text{k}\Omega$ ), the open

circuit potential and the characteristics of the E vs i plot in the low to intermediate current density region were practically identical to those of PEMFCs with thicker membranes ( $> 50 \mu\text{m}$ ), but the cell performance was found to be lower at high current densities. This is probably due to the higher contact resistance between the electrodes and the graphite fixtures. When the compression increased the electronic resistance decreased, and the OCV and the apparent Tafel slope also decreased, but the cell performance showed an improvement at higher current densities. To eliminate the electronic short-circuiting through the membrane, cells with  $40 \mu\text{m}$  thick GORE SELECT™ membranes were prepared and tested. The results showed that the cell performance depended very little on the membrane thickness for current densities up to  $1.0 \text{ A/cm}^2$  when the cathodic reactant gas was air. The data in Figure 6 show that for a PEMFC with a  $40 \mu\text{m}$  thick membrane there is very little difference, at high current densities, between the performance of an electronically shorted MEA and an MEA with no electronic conductivity, however there is a significant difference between the two in the low current density region (see insert in Figure 6).

### **1.3 Work to be Performed in the Next Month**

- Preparation of larger size electrodes ( up to  $200 \text{ cm}^2$ ) with the best electrode composition and determination of the effects of scale-up on cell performance.

## **2. Task 2. Water Management**

Investigators: Hari Dhar\*, Serguey Gamburzev, Omourtag A. Velev, and Frank Simoneaux

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\* BCS Technology, Inc. - subcontractor on this project

## Objectives

The objective of this Task is to eliminate external humidification of the reactant gases for PEMFC stacks operating at the desired current density of  $0.7 \text{ A/cm}^2$  for which the goal is a cell potential of 0.7 V.

### 2.1 Single Cells

BCS supplied CESHHR membrane-electrodes assemblies for testing in single cells and a four cell stack. The performance of the stack was much less satisfactory than that obtained at BCS. Therefore, to verify its own performance data, BCS tested more MEAs in a single cell and a four cell stack. Performance data of the PEMFC with the GORE-SELECT™ membrane, and electrodes with a Pt loading  $2 \text{ mg/cm}^2$  are shown in Figure 6 using  $\text{H}_2/\text{air}$  and  $\text{H}_2/\text{O}_2$  reactants. The performance of the PEMFC with air was about  $500 \text{ mA/cm}^2$  at 0.7 V and 1 atm pressure. With oxygen, the current density under similar conditions was about  $900 \text{ mA/cm}^2$ . In the previous Quarterly Report, we reported that with electrodes containing  $5 \text{ mg/cm}^2$  Pt, the cell potential with air at 0.7 V was about  $700 \text{ mA/cm}^2$ . On the air side, pressure was 1.25 atma. This small overpressure enhances performance. The present performance data are in accordance with the values previously obtained.

Uncatalyzed gas diffusion electrodes (substrate plus diffusion layer) from CESHHR were evaluated at BCS Technology. These electrodes ( $50 \text{ cm}^2$  active area) were catalyzed by procedures developed at BCS. The electrocatalyst loading was  $4.8 \text{ mg Pt/cm}^2$ , the membrane-electrode assembly was prepared using Nafion 112 membrane. The fuel cell rapidly increased in performance after startup, the cell conditioning period being shorter than that observed with E-TEK electrodes. Figure 8 shows the performance with air and with oxygen at atmospheric

pressure. At 0.7 V, the current density in the PEMFC with  $H_2$ /air was about 500 mA/cm<sup>2</sup>, and with  $H_2$ /O<sub>2</sub> the performance was 700 mA/cm<sup>2</sup>. These performances are similar to those observed with E-TEK electrodes of similar electrocatalyst loading. The performance data using the GORE-SELECT™ membrane and electrodes from CESHR are presented in Figure 7. At 0.7 V, the current density was about 0.6 A/cm<sup>2</sup> with air. These data are slightly less satisfactory than those obtained with the E-TEK electrodes.

## 2.2 Cell Stacks

One 3-cell stack of area 50 cm<sup>2</sup> was assembled at BCS Technology, Inc. with MEAs prepared using a Nafion 112 membrane and electrodes containing a Pt loading of 4.5 mg/cm<sup>2</sup>. The performance data of the stack with air and oxygen are given in Figure 8. At 2.1 V (0.7 V per cell), the current density was about 0.48 A/cm<sup>2</sup> with air and about 0.65 A/cm<sup>2</sup> with oxygen. The cells required slight pressurization on the air side of the cell. The individual cell performance is given in Figure 9. The performance of the third cell was found to be slightly lower, and required a rapid flow (flushing) of hydrogen periodically. This problem did not result from the quality of the MEAs used, but was probably due to a design problem associated with stacking or the internal manifolding. The stack was tested at CESHR for performance verification and approximately the same performance was observed as that at BCS. However, problems similar to those noted at BCS were also seen at CESHR.

## 2.3 Work to be Performed in the Next Month

### 2.3.1 *Single Cells*

- Evaluation of thinner membranes such as Nafion 112 and GORE-SELECT™.



- Evaluation of self-humidified MEAs with Nafion 112 and GORE-SELECT™ membranes in larger (100 and 150 cm<sup>2</sup>) area fuel cells. The objective will be to reproduce the performance of smaller cells.

### **2.3.2 Cell Stacks**

- Investigation of the effect of scale-up and cell stacking on performance in four cell stacks using BCS and CESHRE MEAs.

## **3. Task 3. Lightweight Cell Components**

Investigators: Imran J. Kakwan, Frank Simoneaux, and Omourtag A. Velev

### Objectives

The objective of this Task is to identify and test cell components to build a lightweight PEMFC stack.

### **3.1 Compact Lightweight Bipolar Plates**

No work was done during this Quarter.

### **3.2 Work to be Performed in the Next Quarter**

## **4. Task 4: Performance Demonstration in > 250 W Short Stack**

Investigators: James Lee, Imran J. Kakwan, and Omourtag A. Velev.

Status - no work during quarter.

#### **4.1. Work to be Performed in the Next Quarter**

- Studies and analysis of designs for bipolar plates, flow-fields, thermal and water management for a short stack configuration will continue.

#### ***Summary of Expenditures***

The summary of expenditures for this project is presented in Figure 10.

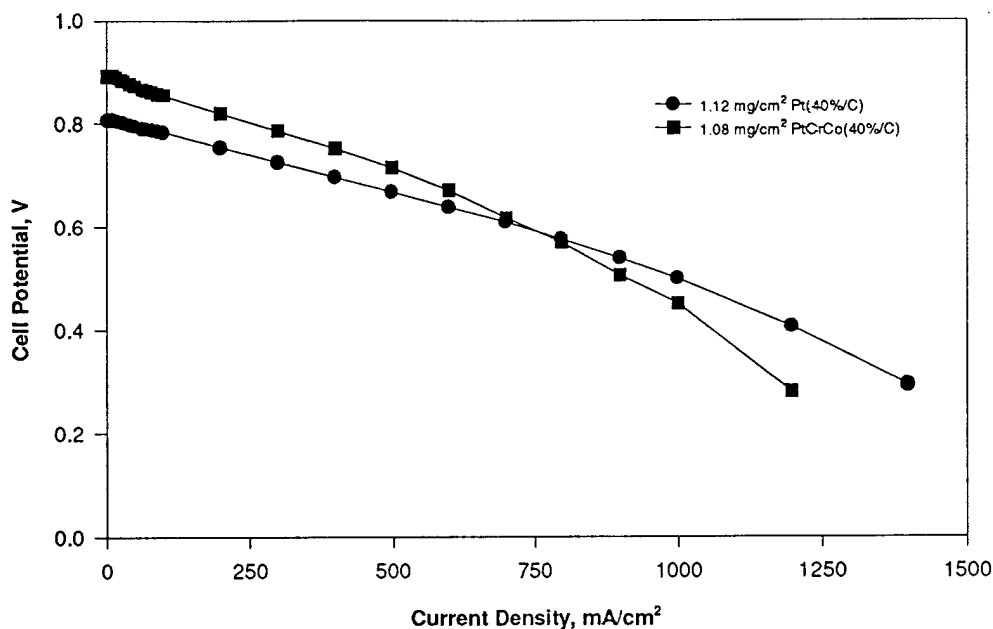


Figure 1 Cell potential vs. current density plots for PEMFCs with different type of electrocatalysts, 5 cm<sup>2</sup> cell, anode Pt loading 0.3 mg/cm<sup>2</sup>, GORE-SELECT 20 μm membrane, temperature 50 °C, atmospheric pressure, reactants humidified.

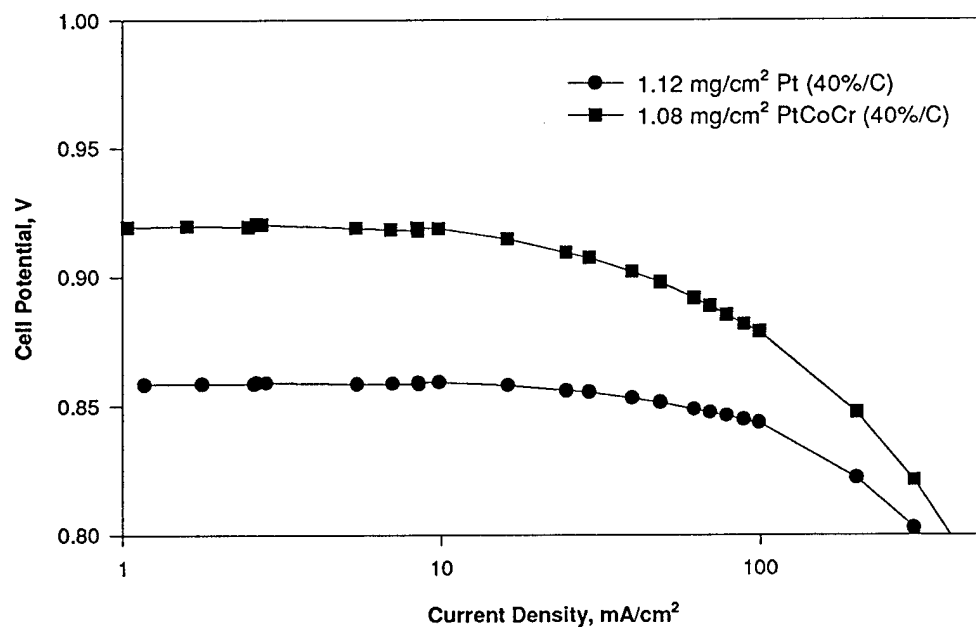


Figure 2 Tafel plot for the data from Figure 1, operating gases hydrogen/oxygen.

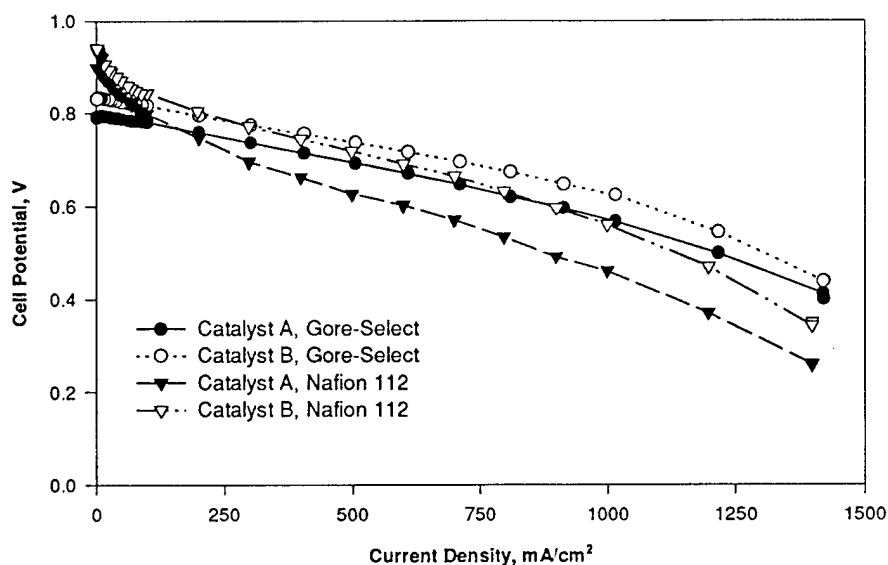


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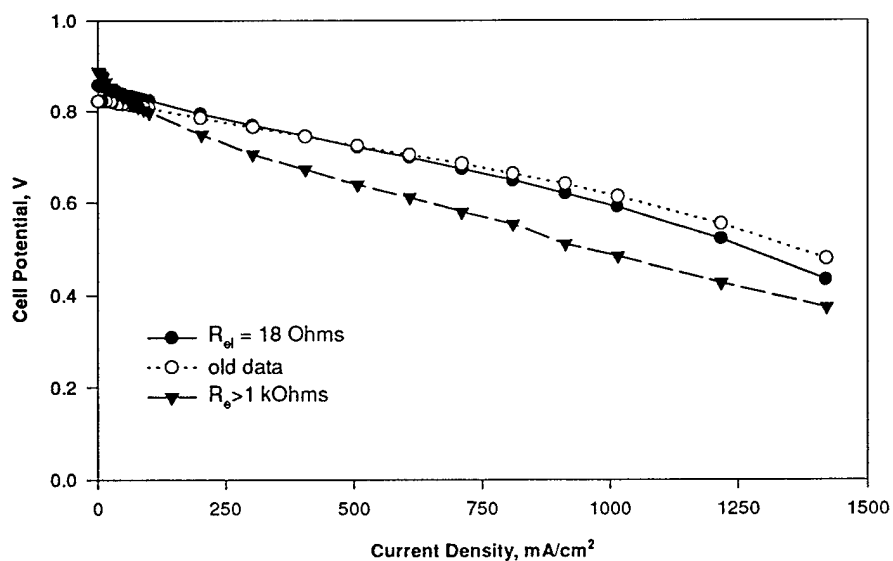


Figure 4 Cell potential vs. current density plots for cells with GORE-SELECT 20 µm membrane with MEAs exhibiting high and low values of electronic resistance. 5 cm<sup>2</sup> cell, temperature 50 °C, atmospheric pressure, humidified hydrogen/air.

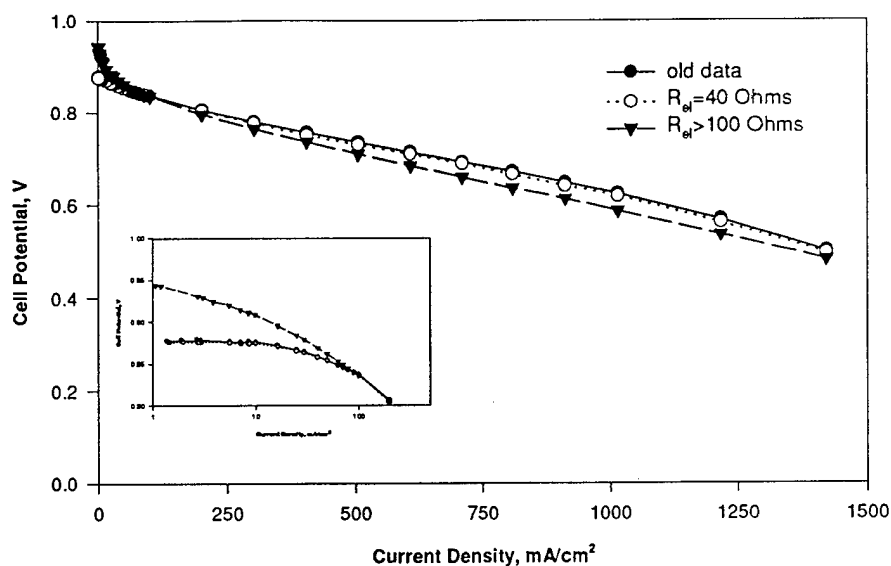


Figure 5 Cell potential vs. current density plots for cells with GORE-SELECT 40  $\mu\text{m}$  membrane with MEAs exhibiting high and low values of electronic resistance. 5  $\text{cm}^2$  cell, temperature 50  $^{\circ}\text{C}$ , atmospheric pressure, humidified hydrogen/air. Insert - Tafel plot of the same data.

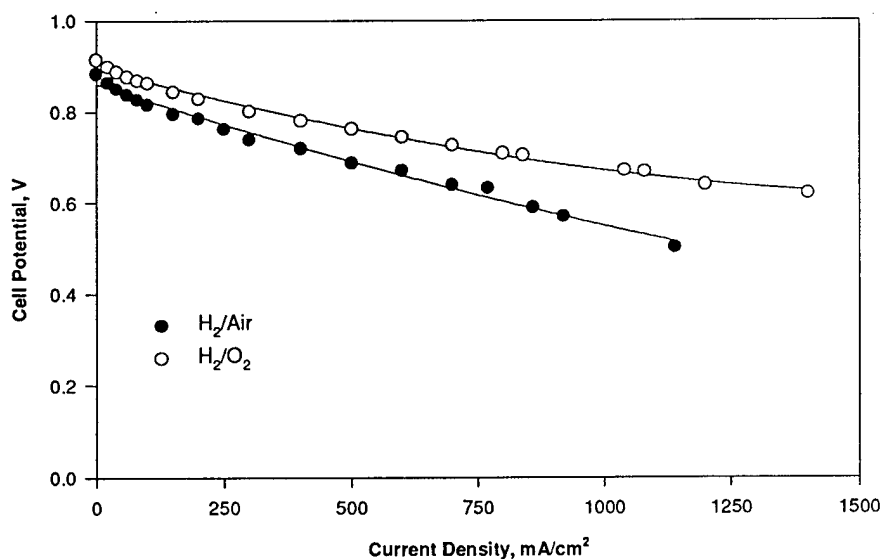


Figure 6 Cell potential vs. current density plots for a cell with GORE-SELECT 20  $\mu\text{m}$ . Electrocatalyst loading 2.0  $\text{mg Pt/cm}^2$ , 50  $\text{cm}^2$  cell, temperature 50  $^{\circ}\text{C}$ , atmospheric pressure, dry reactant gases. Test performed at BCS Inc..

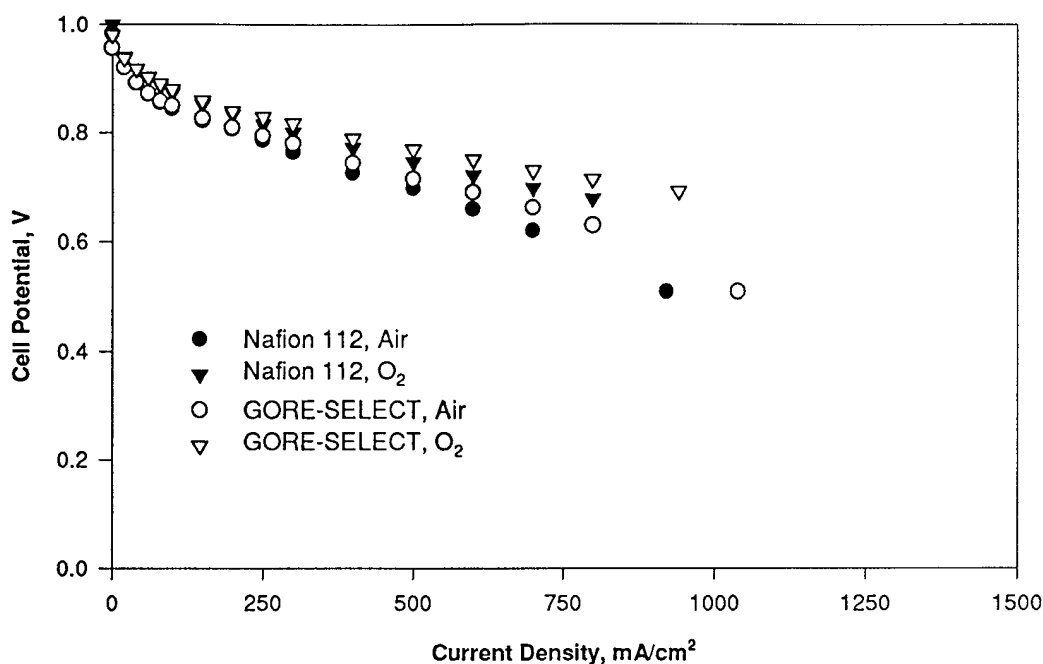


Figure 7 Cell potential vs. current density plots for cells with gas diffusion electrodes made at CESH, catalyst layer deposited at BCS technology. Electrocatalyst loading 4.8 mg Pt/cm<sup>2</sup>, 50 cm<sup>2</sup> cell, temperature 50 °C, atmospheric pressure, dry reactant gases. Tests performed at BCS Inc.

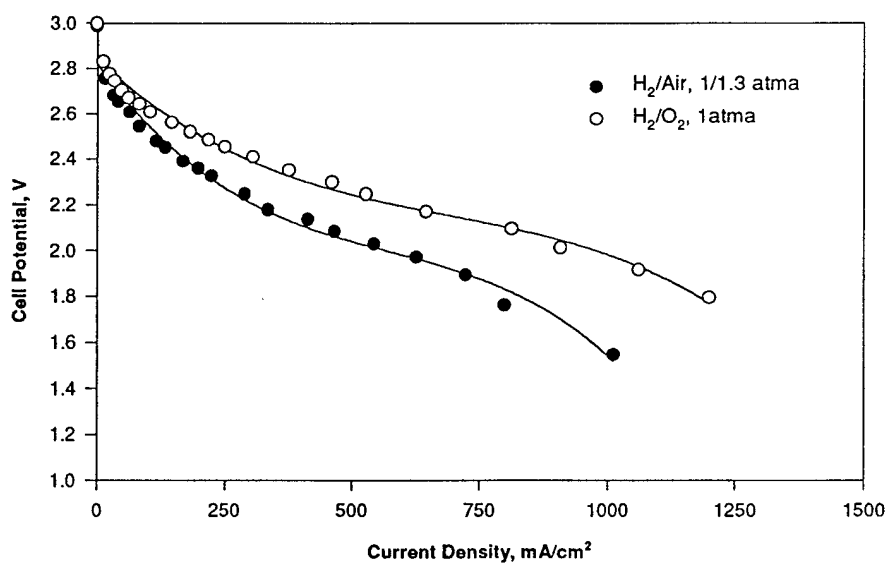


Figure 8 Cell potential vs. current density plots for 3-cell stack. Membrane Nafion 112, Electrocatalyst loading 4.5 mg Pt/cm<sup>2</sup>, 50 cm<sup>2</sup> cells, temperature 50 °C, dry reactant gases. Test performed at BCS Technology Inc..

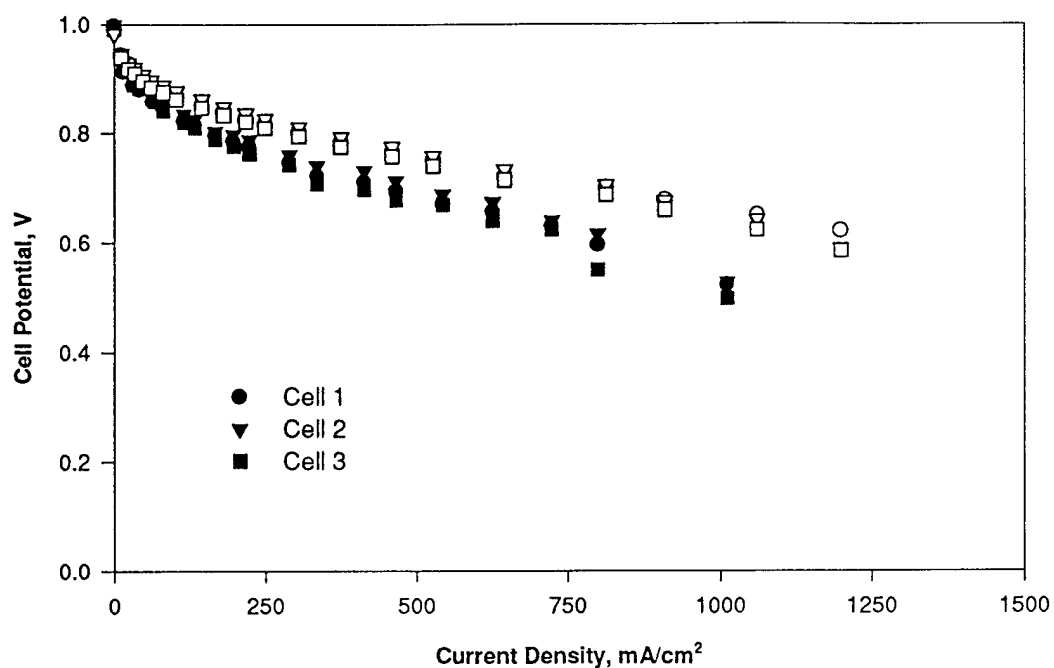


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Monthly and Cumulative Expenditures since October 1994

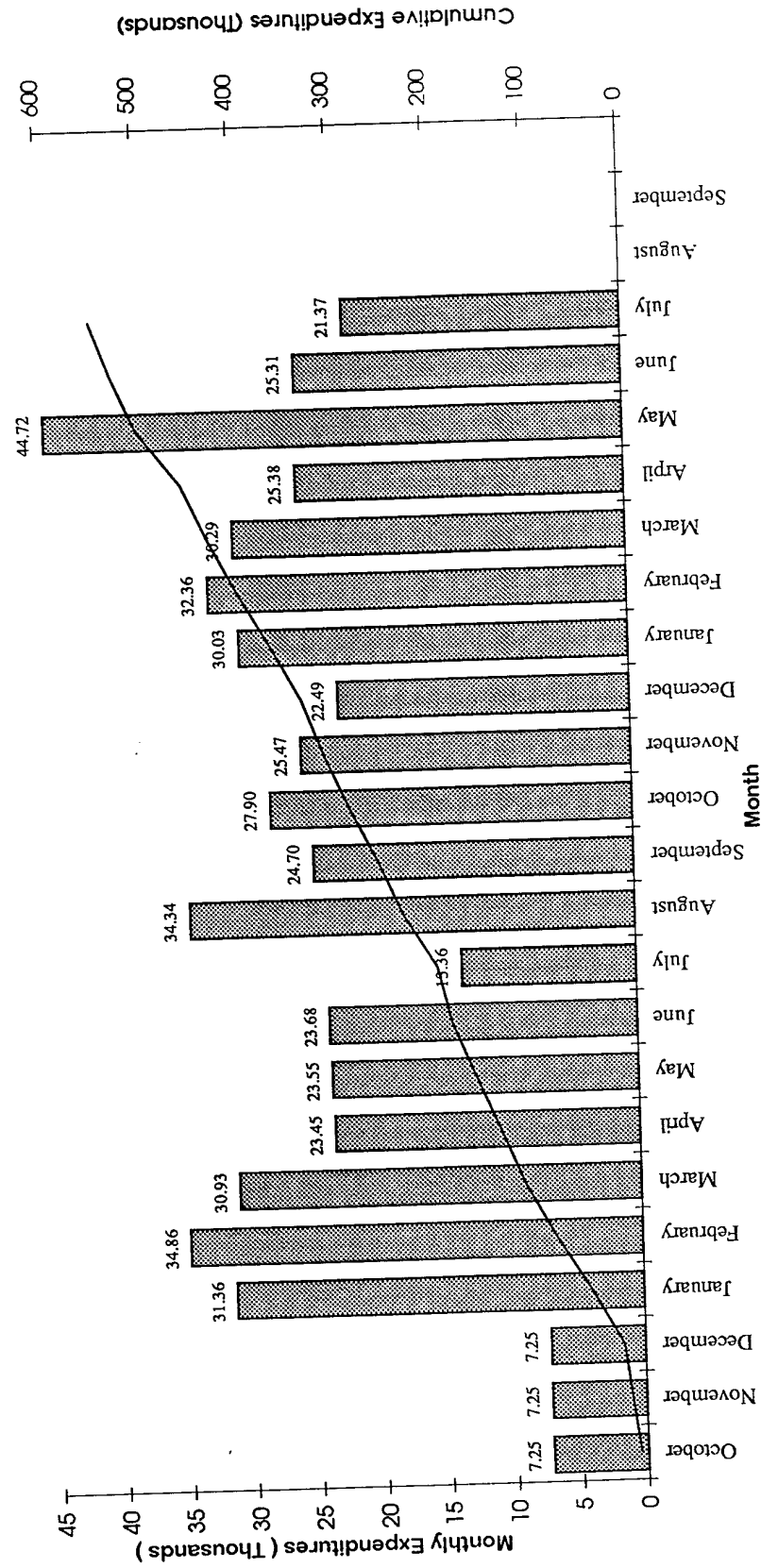


Figure 10 Summary of expenditures - monthly and running totals.



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